The Investment Response to Temporary Commodity Price Shocks

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Abstract:

The paper is concerned with the investment response to temporary trade shocks when capital in the commodity and import-competing sectors is irreversible once installed. Previous literature has argued in general terms that investment is likely to rise in response to sharp relative price movements because the return to capital in one of the sectors will increase. A rigorous model of investment under uncertainty in the two-sector commodity price shocks context is developed and used to investigate this issue. It is shown that investment booms in response to commodity price shocks are likely but not certain to occur and a boom at the end of the shock may also be expected. The predictions of the theory are shown to be consistent with the evidence from a small sample of countries during the late 1970s coffee/cocoa boom.

Introduction

This paper is concerned with the investment response to temporary commodity price shocks when capital is sector specific and irreversible once installed. It makes use of the insights of the irreversibility and investment literature to develop a rigorous two sector model of the optimal investment response to a temporary price shock. The model is simulated across a range of possible parameter values and the output compared with the actual investment responses of a small sample of countries to the late 1970s coffee/cocoa boom.

That boom has stimulated a substantial literature on trade shocks[1] but formal work within it has tended to focus on the consumption/saving (rather than investment) response to price shocks and policy questions. These issues are extremely important, both because a key policy question has been whether the private sector savings response to a temporary shock would be appropriate (and hence if so there would be no need for government to play a custodial role by taxing the windfall from the boom), and also because the general policy responses have often been regarded as severely sub-optimal. Hence this literature has tended not to emphasise the investment response to relative price changes which is the focus of the current paper. This shift of emphasis is also natural because relative price effects were often small or absent in the 1970s (as we show below) because the great majority of developing countries stabilised domestic producer prices of commodities. With almost all price stabilisation schemes and marketing board arrangements abolished from the late 1980s, relative price effects are likely to be much more important in the future.[2] The trade theory literature[3] has also examined the effects of terms of trade changes on a number of variables but also without examining the combination of sector specific irreversibility and uncertainty that is the focus of the current paper.

Hence the key contribution of the current paper is its modelling of investment dynamics in response to relative price changes in the presence of uncertainty about the duration of the current price and irreversibility of capital at the sectoral level. The analysis is intended to improve our understanding of when investment booms are likely to occur as commodity prices (or the terms of trade) fluctuate. Bevan, Collier and Gunning (1990) provide the key intuition in that a sizeable increase in the relative commodity price, a "trade shock", will greatly increase the return to capital in the commodity sector and thus stimulate investment. If non-tradeable capital goods are important in production that investment boom will translate into a non-tradeable capital goods ("construction") boom also. Equally a large fall in the commodity price will give rise to the same effects in reverse with increased investment in the import-competing sector. This paper goes both much further and less far than that argument. It goes further in that formal modelling of the investment responses of both sectors allows for a much more precise prediction of when investment booms will occur and their possible size. An important point here is that when the favoured sector expands in response to a price change the other sector will allow its capital stock to depreciate. If depreciation is at a plausible (low) rate the combined capital stock increases but the change in aggregate investment is ambiguous: compared with before the price shock the favoured sector is investing more but the other sector will no longer be undertaking replacement investment. The net effect of these changes depends on the size of the investment response in the favoured sector (which in turn will depend on expectations about the duration of the boom and the severity of the losses from irreversibility that would occur if or when the boom is reversed), the relative size of the two sectors, and their capital intensities. The paper does not, however, include non-tradeable capital goods and hence its predictions concern investment booms rather than construction booms in particular, and while we draw general conclusions on the latter these are not based on formal analysis.

It may be noted that analyses of this type assume that commodity price changes may be characterised by relatively large infrequent swings so discrete shock episodes may be identified. This is an entirely plausible procedure in relation to the coffee and cocoa price shocks of the late 1970s but in general it might be argued that other commodity prices may be better characterised by ongoing volatility in which price changes are frequent and less readily divided into discrete episodes. It is clear that there is no distinct dividing line between these two descriptions of price movements but the results developed below are based on the assumption of a discrete shock with defined start and end dates. Hence the model is less informative about investment dynamics in response to higher frequency volatility except in so far as the typical price innovation has persistent effects[4] whereupon its results will carry over to some extent.

While the investment responses outlined above are the main focus of the paper we also analyse their implications for three related issues as follows.

First the relationship between investment and the terms of trade has been difficult to establish in empirical work with different studies finding different signs to the relationship (see Serven, 1997 for a recent overview). The paper shows why this may be so, in particular by showing that investment is driven as much by changes in the terms of trade as in its level.

Second, we examine in a very stylised way possible feedback effects onto world commodity prices from the supply response, partly driven by investment, to exogenous changes in those prices. The model clarifies how the supply response is likely to vary during a commodity price boom and also shows that prices after a shock may be lower than their steady state values as a result of the irreversibility of capital acquired during the boom: investment during the boom raises the capital stock and this stock remains higher (and hence prices are lower) for some time after the shock until depreciation allows a new steady state to be reached. Hence irreversibility implies that a temporary price shock may have long-lasting supply effects and this may help to explain part of the serial correlation in commodity prices that has otherwise been difficult to rationalise (see Deaton and Laroque, 1995, for a recent discussion).

Third our formal model assumes access to a perfect world capital market (a natural, if unrealistic, benchmark case) but the investment dynamics that it predicts may readily be compared with what would occur if investment had to be financed from internally generated funds. This area is complex and there are a number of different modelling approaches that may be taken but we show that financing constraints, while still important, do not prevent sizeable investment responses to relative price swings. This reflects the fact that the "invest in good times, allow the capital stock to depreciate in bad times" nature of optimal irreversible investment decisions means that times when unconstrained investment would be positive tend to correlate with times when internal funds are higher than usual.

The paper is structured as follows. Section 1 outlines the model while Section 2 simulates it in order to generate different scenarios and possible results for the investment dynamics in response to commodity price shocks. This constitutes the core of the analysis but we also compare the results with the actual investment data for a small sample of countries during the late-1970s coffee and cocoa boom. The model simulations also show why the empirical links between the terms of trade and investment may be difficult to pin down and suggests possible alternative specifications. Sections 3 and 4 look at the feedback effects on world prices and the role of financing constraints discussed above. Section 5 concludes.

1. The Model[5]

It is assumed that there are two competitive sectors with physical output X and M of the commodity and import-competing goods respectively. These outputs are produced using Cobb Douglas technology given by (1) which we assume for simplicity to be symmetric in the α and β parameters. The notation is l_i for labour in sector i, K_i for the sectoral capital stock and F_i a further fixed factor in each sector (discussed below).

$$X = l_x^{\alpha} K_x^{\beta} F_x^{1-\alpha-\beta} \qquad M = l_m^{\alpha} K_m^{\beta} F_m^{1-\alpha-\beta} \tag{1}$$

The labour force in the economy is fixed but labour is assumed to be fully mobile between sectors so the wage rate in each will equalise in each period. Without loss of generality we normalise the aggregate labour endowment to unity so $l_m=1-l_x$.

Capital goods are sector specific and all imported. They are assumed to be available in elastic supply from the world market at constant prices P_{Kx} and P_{Km} (non-linear adjustment costs are not considered) but irreversible once installed so the rates of depreciation, δ_x and δ_m, represent the upper limit on the speed with which the sectoral capital stocks may shrink. These assumptions imply a major asymmetry between the upward and downward flexibility of the sectoral capital stocks which strongly drives the dynamics of the investment responses to price changes. Two further assumptions are that the capital goods are used in production and neither stored nor scrapped, and that there is a delivery or time to build lag between the decision to invest and the new capital goods becoming productive. In the simulations below we set this lag at one and four years in turn, the former corresponding approximately to equipment-type goods and the latter to tree crops where new trees take some time to mature before becoming productive.

We also assume that the economy has access to a perfect world capital market with (real) interest rate, r^*. This assumption, together with the absence of non-tradeable consumer goods, separates production and consumption decisions in the economy and makes risk neutrality an appropriate assumption such that investment decisions will depend solely on expected returns. Hence the structure of the model is focused tightly on the investment response to changes in the sectoral returns to capital in the presence of uncertainty about the continuation of the price shock. The motivation for this is that these factors are missing from the current literature.

It is assumed that there is free entry to each sector which, in relation to irreversibility and investment models, means that there is no option value of waiting since if the irreversibility constraint is not binding expected present value net returns (carefully specified to include future states in which it may bind and losses occur) will be driven to zero. Irreversibility still matters, however, since there is an entry asymmetry between good and bad states of the world for the return to capital. In a good state firms may enter without any barriers but in a bad state not only will there be no new entry but existing firms cannot exit due to irreversibility. This asymmetry is incorporated in the equilibrium condition for the capital stock by means of taking into account the future entry of new capital in good states when calculating expected returns.

The third factor of production in each sector, given by F_x and F_m in (1), is assumed to be entirely fixed, both by sector and over time. Given the international mobility of capital this factor is necessary to avoid complete specialisation and may be interpreted as being sector specific human capital or natural resources in inelastic supply (at least over the timeframe of a few years considered here). For agricultural commodities this fixed factor may be interpreted as being land. For simplicity we choose units so $F_x=F_m$ to avoid their ratio cluttering the expressions below.

The remaining notation comprises P_x and P_m for the pre-shock world prices of X and M respectively. We make the M good the numeraire and hence $P_m=1$ and all other prices are relative to this price. When the shock occurs the relative price of the commodity rises to $P_x(1+s)$, where s is the proportionate size of the shock, and falls back to P_x when the shock is reversed. The output prices determine the economy's position on its production possibility frontier while the prices of capital goods, P_{Kx} and P_{Km}, together with the other parameters determine the position of that frontier given that the sectoral capital stocks are endogenous to the model rather than being fixed endowments. We assume that the prices of the capital goods are constant and in the simulations for simplicity we set them equal to each other, P_x being varied to change the initial conditions at the start of the shock.

Given (1) we have the following standard results for the return (r_i) and cost (c_i) of capital by sector. We include the term (1+s) though note that s is set to zero before and after the shock.

$$r_x = \frac{P_x(1+s)\beta l_x^{\alpha} F_x^{1-\alpha-\beta}}{K_x^{1-\beta}} \qquad c_x = P_{K_x}(r^* + \delta_x) \tag{2}$$

$$r_m = \frac{P_m \beta l_m^{\alpha} F_m^{1-\alpha-\beta}}{K_m^{1-\beta}} \qquad c_m = P_{K_m}(r^* + \delta_m) \tag{3}$$

Given that labour is assumed fully mobile between the two sectors the wage rate, w, will equalise so $w_x=w_m$ and it is straightforward to show that:

$$\left(\frac{l_x}{l_m}\right)^{1-\alpha} = \frac{P_x K_x^{\beta}}{P_m(1+t_m)K_m^{\beta}} \tag{4}$$

It is convenient to derive results relative to the values that obtained before the shock (given by superscript 0 corresponding to period 0 in the simulations) and we also want l_x and l_m separately so it is helpful to change (4) to give l_x ($=1-l_m$) in (5) by making use of (1) to (3).

$$= \frac{(1+s)^{\frac{1}{1-\alpha}}\ [P_x(\frac{P_{Km}}{P_{Kx}})^{\beta}]^{\frac{1}{1-\alpha-\beta}}(\frac{r^*+\delta_m}{r^*+\delta_x})^{\frac{\beta}{1-\alpha-\beta}}(\frac{K_x}{K_x^0}\frac{K_m^0}{K_m})^{\frac{\beta}{1-\alpha}}}{1\ +\ (1+s)^{\frac{1}{1-\alpha}}\ [P_x(\frac{P_{Km}}{P_{Kx}})]^{\frac{1}{1-\alpha-\beta}}(\frac{r^*+\delta_m}{r^*+\delta_x})^{\frac{\beta}{1-\alpha-\beta}}(\frac{K_x}{K_x^0}\frac{K_m^0}{K_m})^{\frac{\beta}{1-\alpha}}} \qquad (5)$$

Having laid out the core components of the model we specify the pre-shock situation, the response to the shock and the subsequent adjustment when shock reversal occurs. For simplicity we assume that the shock is not anticipated (while commenting later on the implications of changing this assumption) and that the pre-shock value of P_x has been in place long enough for the sectoral capital stocks to adjust such that the return to capital is equal to its cost in each case.

The commodity price shock takes the form of P_x changing to $P_x(1+s)$. By assumption investment involves a lag (of initially one period, the case we outline in the discussion) so the sectoral capital stocks in the first period of reform are pre-determined. By contrast labour is fully mobile and hence an immediate labour reallocation towards the export sector will take place shown by (5). The shock implies an immediate reduction in the return to capital in the import competing sector and the loss of labour exacerbates this. The gain of labour in the export sector has the opposite effect on the return to capital there. In this first period investment decisions are taken to determine the sectoral capital stocks in the following period.

If the shock were permanent the path of these capital stocks over time would be that M sector capital would depreciate gradually down to its pre-shock value and X sector capital would expand upwards to its new steady state, at each point earning a zero net return, the size of K_x being determined by this condition combined with the rate at which the M sector releases labour as K_m depreciates.

Turning to a temporary trade shock, defined by agents perceiving a probability of shock reversal at each point, we anticipate increases in K_x, the key issue being by how much given the risk of an excessively large capital stock in place after the end of the shock due to irreversibility. Decreases in K_m, following the reduction in its return to capital during the shock, will occur gradually through depreciation until it reaches a steady state (assuming that reversal has not already taken place). K_x will face a binding irreversibility constraint if reversal occurs and hence the magnitude and probability of the losses that would result must be taken into account in forward looking investment decisions while reform continues. We adopt the simplifying assumption that shock reversal (with the relative commodity price returning to its pre-reform value) is, or at least is perceived to be, permanent. If reversal does take place the roles of the sectoral capital stocks are reversed in that K_x will depreciate gradually back to its pre-reform level and K_m will expand to its equivalent point, the expansion path being determined by a zero profits condition on K_m and the gradual reallocation of labour back to the M sector as K_x depreciates. Hence the post-reversal outcome is relatively simple and it is this, combined with the probability of it occurring, which determines the equilibrium expansion of K_x while reform continues.

More formally, at a given time, s, following reform but before any reversal and assuming that the initial value of K_x is low enough for the irreversibility constraint not to bind, the desired and actual capital stock in the X sector (assuming risk neutrality) will satisfy:

$$E_{s-1}[\Sigma_{t=s}^{\infty}[[r_x^t(K_x^t)-c_x](\frac{1-\delta_x}{1+r^*})^{(t-s)}] = 0 \tag{6}$$

This is the standard equilibrium condition by which the expected present value of net returns to a unit of capital invested at some time s (the decision to invest having been taken at t=s-1) is equated to zero.[6] The terms $r_x(.)$ and c_x give the return and cost of a unit of capital and hence the term $(1-\delta_x)^{(t-s)}$ appears because this gives the amount of an initial unit of capital left after s-t periods. It is helpful to separate out period s from (6) which gives:

$$\begin{aligned}&(1-p)[r_x^s(K_x^s)|_{s=s}-c_x]+p[r_x^s(K_x^s)|_{s=0}-c_x]\\&+E_{s-1}[\ \Sigma_{t=s+1}^{\infty}[[r_x^t(K_x^t)-c_x](\frac{1-\delta_x}{1+r^*})^{(t-s)}]\ ] = 0\end{aligned} \tag{7}$$

This shows that the expected net return for period s (which depends on K_x at that time) depends on the expected net return in the periods that follow it in order that the expected net present value as a whole is zero to reflect free entry at time s. At this point the effect of the entry asymmetry discussed earlier becomes important. If reform continues at s, free entry means that equilibrium condition (6) will be repeated and hence seen from the perspective of time s-1, the expected present value of net returns if reform continues must be zero. On the other hand if reform is reversed, irreversibility implies that net returns will become negative for a number of periods before depreciation reduces K_x to the point where net returns are zero once again. This asymmetry implies that a zero should be inserted within the summation of the second line of (7) for future scenarios where reform continues. Only future losses with reform reversal, together with their associated probability, need appear. Denoting T_x^s as the number of periods when losses are made post reversal and making use of these arguments means that (7) may be transformed to:

$$\begin{aligned}&(1-p)[r_x^s(K_x^s)|_{s=s}-c_x]\\&+\ p[\Sigma_{t=s}^{t=s+T_x^s}[[r_x^t(K_x^s(1-\delta_x)^{(t-s)})|_{s=0}-c_x](\frac{1-\delta_x}{1+r^*})^{(t-s)}] = 0\end{aligned} \tag{8}$$

In (8), p is the perceived probability of reform reversal each period (which we take to be constant) and the K_x term within the summation sign is given in relation to K_x at time s and the number of periods of depreciation because net losses are being made during the interval s to s+T_x^s and investment in the X sector will be zero.

Equilibrium condition (8) shows that investment will take place for time s to the point where the capital stock gives an expected net return in that period equal to the present value of the losses that would be incurred after that period if liberalisation is reversed at t=s, weighted by the probability of that event. As the capital stock expands for time s, the period s return will fall and the size of future losses will rise because a higher K_x will be inherited at the time of reversal. Forward looking investment behaviour will balance the period s return if reform continues against expected losses if it is reversed which implies that the current period return will not be driven to zero as would be the case if the liberalisation was fully credible.

Hence (8) confirms the intuitive idea that an expectation of reversal must weaken the investment response to reform though it also highlights the fact that an improved current period return following the shock will encourage commodity sector investment. Given the assumption that reversal entails a return to the pre-shock value of P_x, (8) implies that the investment response in the X sector must be positive because there is an increased current period return and the worst outcome in the future is the same as before the shock. As noted above, however, a positive investment response in the X sector will not necessarily lead to a positive aggregate investment response given that investment in the M sector will be zero during the transition after reform and lower in the steady state than its initial value. In turn a higher K_x and lower K_m implies that real income will increase with liberalisation whatever the perceived probability of reversal.

In order to facilitate numerical simulations we transform (8) by assuming Cobb Douglas technology outlined above and also express K_x while reform continues relative to its credible free trade value.

$$\left(\frac{K_x^s}{K_x^0}\right)^{1-\beta} = \frac{(1+s)\left(\frac{l_x^t}{l_x^0}\right)^{\alpha} + p\ \Sigma_{t=s}^{t=s+T_x^s}\left(\frac{l_x^s}{l_x^0}\right)^{\alpha}\left[\frac{(1-\delta_x)^{\beta}}{(1+r^*)}\right]^{t-s}}{1 + p\frac{(1-\delta_x)}{(r^*+\delta_x)}\left[1-\left(\frac{1-\delta_x}{1+r^*}\right)^{T_x^s}\right]} \tag{9}$$

The system is completed by the labour allocation given by (5) and the value of K_m which is given by its depreciation path from its initial value until it reaches its post reform steady state value, K_m^s given by (10) which is derived straightforwardly from a zero expected net return condition given the one period investment lag.

$$(1-p)[r(K_m^{ss})|_{s=s}-c_m] + p[r(K_m^{ss})|_{s=0}-c_m] = 0 \tag{10}$$

Which for Cobb-Douglas technology may be expressed by:

$$\frac{K_m^{ss}}{K_m^0} = \left[\ (1-p)\left(\frac{l_m}{l_m^0}|_{s=s}\right)^{\alpha} + p\left(\frac{l_m}{l_m^0}|_{s=0}\right)^{\alpha}\ \right]^{\frac{1}{1-\beta}} \tag{11}$$

After reversal (5) continues to hold, K_x depreciates down to its initial pre-shock level and K_m increases to its pre-shock value, the pace of expansion being determined by a zero profits condition combined with the depreciation path of K_x which affects the return to K_m through the release of labour.

The discussion and expressions above have assumed that the delivery or time to build lag before new investment becomes productive is one year. The extension to the four year lag for the commodity sector (we assume that the lag for the M sector remains one year) is straightforward. The structure of equations (6)-(9) remains the same but we replace (1-p), the probability of a continued shock next period, with $(1-p)^4$ which is the probability of a continued shock in four periods time. In turn this means that we replace p in the expressions with $[1-(1-p)^4]$. The longer lag reduces the probability of a favourable shock state at the time that this period's investment becomes productive and hence the investment response to the shock is much smaller. This is partly a reflection of the assumption that the K_m lag remains unchanged (since a longer lag there would slow down the post-reversal K_m expansion which reduces the return to X sector capital but even if this was allowed for the lower probability of a favourable post-lag P_x would still reduce the investment response.

Before simulating the model above we briefly note the implications of the trade shock being anticipated. Given that the shock increases the return to capital in the X sector and reduces it in the M sector, a positive perceived probability of reform will tend to increase K_x and reduce K_m prior to reform. In turn this implies a faster post-reform adjustment to the steady state but will not affect the latter since it depends solely on the probability of reversal.

2. The Investment Response to a Trade Shock

This section reports the core results of the paper concerning the aggregate investment response (based on the underlying sectoral responses) in response to a temporary trade shock. Models of the type set out above unfortunately do not readily generate tractable solutions and hence simulation is necessary. For this we use the parameter assumptions set out in the Appendix and present the results in Figures 1-3 below. The probability of shock reversal is set at 0.25 per period while the shock continues and hence the initial expected duration of the shock is four years. Figure 1 shows the path of aggregate investment and the commodity price assuming that shock reversal does take place after four years while Figures 2 and 3 assume two and six year shock durations. In each figure the left hand charts assume a one period lag in the X sector while the right hand charts extend this to four years. In addition the top pair of charts assume that before the shock the X sector capital stock is relatively large compared with the initial M sector capital stock, the middle pair of charts imposes symmetry between them while the lower charts assume that the X sector is relatively small before the shock. In addition the axes across all three figures are standardised to facilitate visual comparisons. It may also be noted that we show investment expenditure taking place straightaway even though the new capital goods will become productive only after the lag of one or four years.

We first consider Figure 1, which assumes a shock duration of four years, from which it may be noted that the aggregate investment series show spikes or jumps as well as more gradual changes. These reflect the absence of adjustment costs in the model which gives rise to rapid capital adjustments if desired though more gradual changes are also present following the shock and its reversal since after an initial adjustment the favoured sector (X during the shock, M after its reversal) expands more slowly as the other sector's capital stock gradually depreciates. If adjustment costs were included the rapid adjustments would be smoothed but we may anticipate that the overall profile of the series would not otherwise change.

It is clear from the charts, particularly Figure 1(c), the symmetric short lag case which is a natural benchmark, that aggregate investment tends to respond to both the occurrence of the shock and its reversal. It may be recalled that after a change in relative prices the favoured sector expands its capital stock relatively rapidly to take advantage of the new conditions (though as argued above less so than if the shock were permanent) while the other sector stops replacement investment in order to allow its capital stock to depreciate. The net effect of these is shown to be positive in the first period of the shock since the upward adjustment in the favoured sector is initially large but subsequently the lower investment in the non-favoured sector dominates and aggregate investment is lower than before the shock or shock reversal. This chain of events is present after a large upward or downward movement in the relative commodity price since there is one favoured sector and one non-favoured sector in each case. Hence a potential investment boom is predicted by the theory both at the start and the end of the shocks modelled here. In Figure 1(c) we impose symmetry on the initial sizes of the capital stocks and there is an investment boom of comparable magnitude in periods 1 and 5 which correspond to the start and end of the shock.

Figure 1(a) and 1(e) show that the relative size of the capital stocks is important in determining the presence and relative size of these investment booms. In Figure 1(a) the X sector is relatively large and hence its expansion during the shock dominates the fall in M sector investment while that capital stock depreciates, and in turn at the end of the shock the zero investment in the X sector (to allow its capital stock to depreciate to its new post-shock steady state) dominates the expansion of investment in the M sector such that there is no post-shock investment boom. In Figure 1(e) the relative sizes are reversed and the investment boom at the start of the shock is smaller and that at the end of the boom much larger.

The right hand charts in Figure 1, which assume a four year investment lag, share this pattern of the relative sizes of aggregate investment at the beginning and end of the shock but also show very strongly that the initial aggregate investment response is at most zero and often negative. This reflects the much smaller expansion in K_x due to the long lag such that the probability of the shock continuing at the time that new capital becomes productive is greatly reduced. This factor does not alter the post-shock expansion of K_m, both because we assume that its investment lag remains at one year and also because the reversal of the shock is assumed to be permanent.

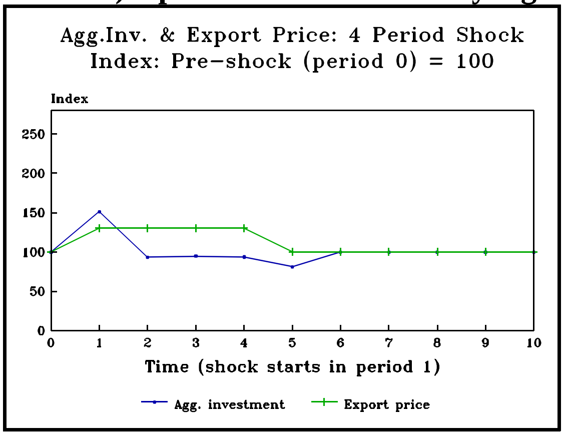
Figures 2 and 3 show how things change if the shock in fact lasts for two or six years respectively. A similar pattern of possible investment booms at the start and end of the shock and the role of sector sizes is seen but in addition the post-shock investment boom is smaller for the two year shocks and much larger for the six year shocks. This results from the amount of time the M sector capital stock has had to depreciate during the shock. The steady state during the shock (assuming that it continues) is reached only after five to seven years and up to that time K_m will continue to depreciate and hence investment in that sector will be larger at the end of the shock the longer the shock duration.

Hence these simulations have broadly confirmed the prediction of the trade shocks literature of an investment boom in response to a commodity price shock (and with it the likelihood of a construction boom if non-tradeable capital "construction" goods are present) though they have clarified a number of points. First that similar investment booms may be anticipated at the end of a shock and these may be larger than the initial boom depending on the relative size of the two sectors and the duration of the shock. Second that an investment boom at the start of the shock is not certain (even in the absence of damping effects from adjustment costs) because the increase in X sector investment may be dominated by the reduction in M sector investment (to zero) at that time, particularly if a long delivery lag is present because that reduces the desired expansion of the commodity sector.

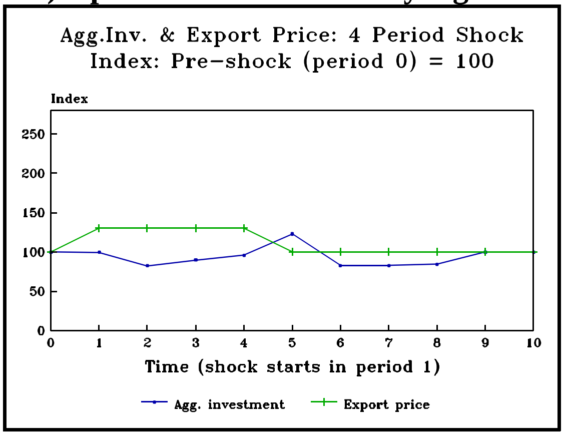
FIGURE 1: AGGREGATE INVESTMENT, 4 PERIOD SHOCK

LARGE INITIAL K_x/K_m

a) 1 period X sector delivery lag

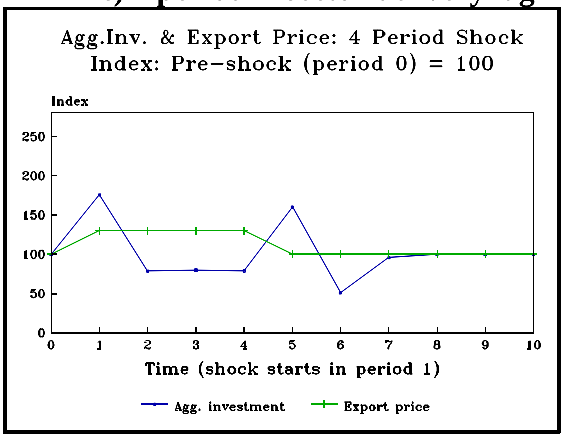


b) 4 period X sector delivery lag

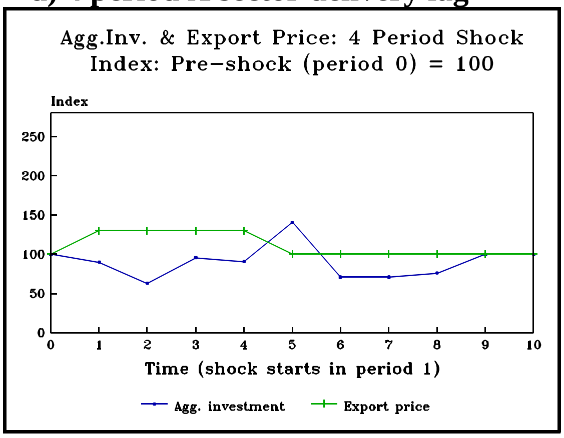


SYMMETRIC INITIAL K_x/K_m

c) 1 period X sector delivery lag

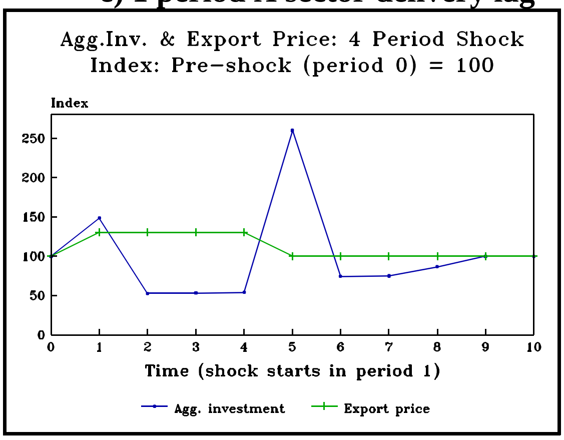


d) 4 period X sector delivery lag



SMALL INITIAL K_x/K_m

e) 1 period X sector delivery lag



f) 4 period X sector delivery lag

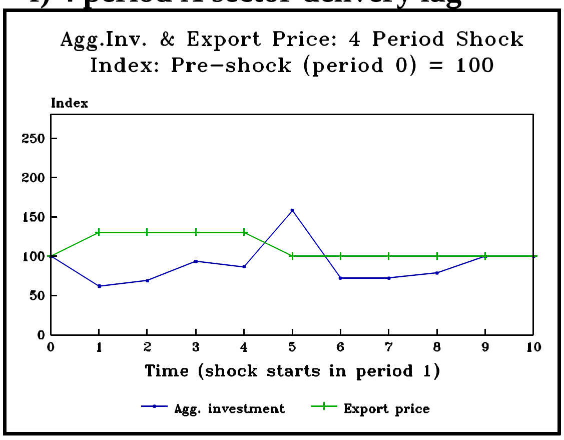
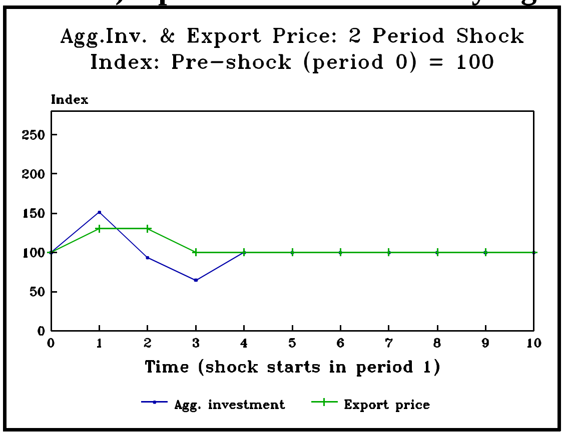


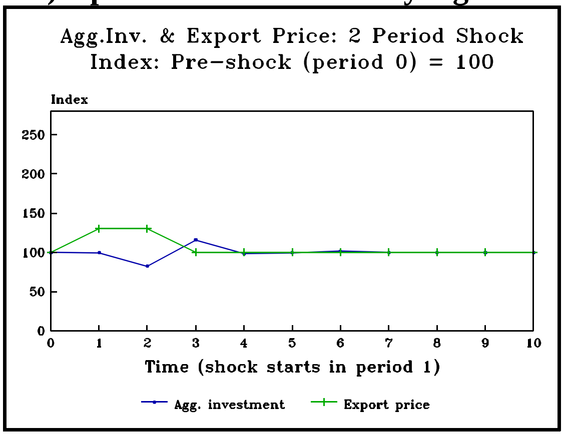
FIGURE 2: AGGREGATE INVESTMENT, 2 PERIOD SHOCK

LARGE INITIAL K_x/K_m

a) 1 period X sector delivery lag

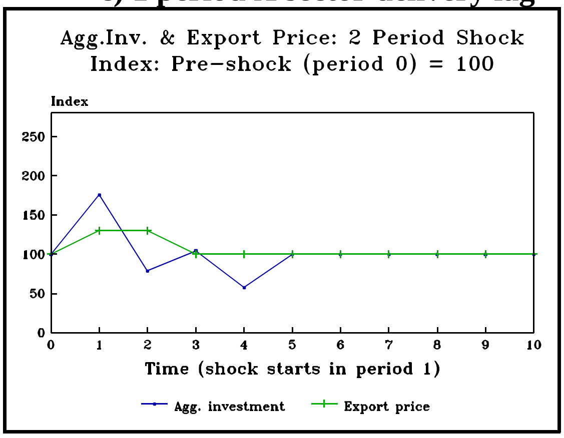


b) 4 period X sector delivery lag

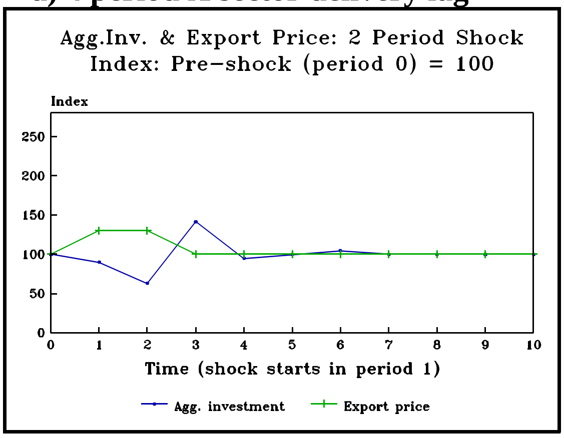


SYMMETRIC INITIAL K_x/K_m

c) 1 period X sector delivery lag

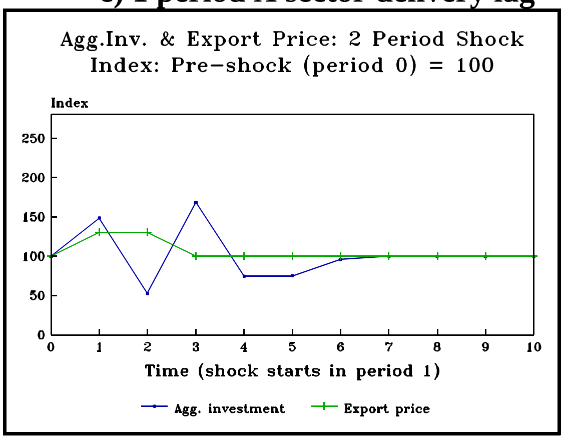


d) 4 period X sector delivery lag



SMALL INITIAL K_x/K_m

e) 1 period X sector delivery lag



f) 4 period X sector delivery lag

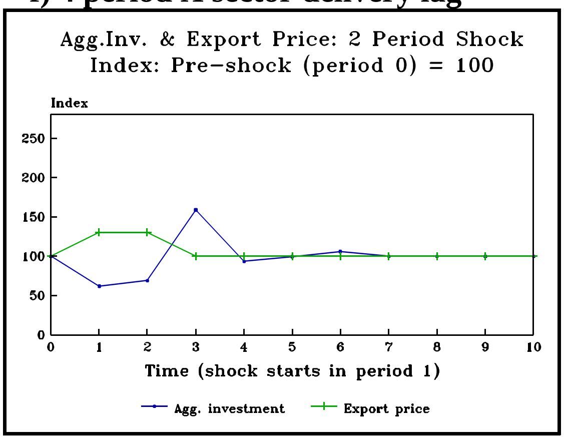
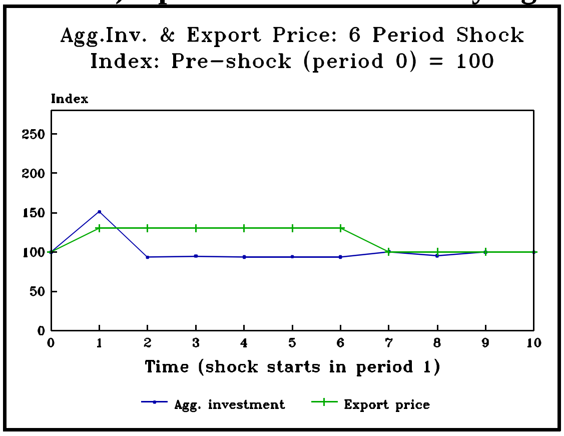


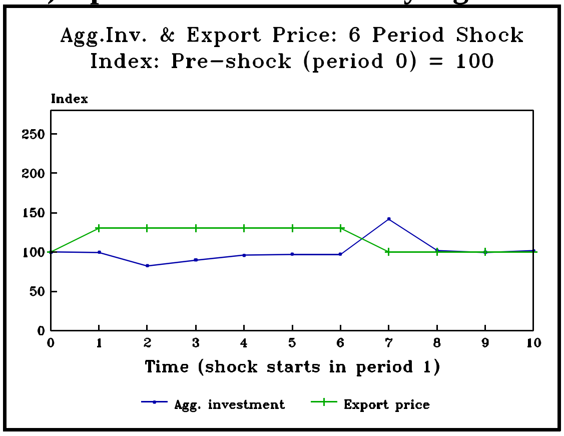
FIGURE 3: AGGREGATE INVESTMENT, 6 PERIOD SHOCK

LARGE INITIAL K_x/K_m

a) 1 period X sector delivery lag

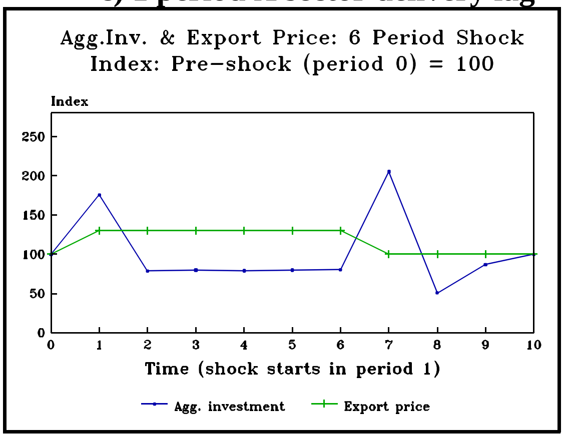


b) 4 period X sector delivery lag

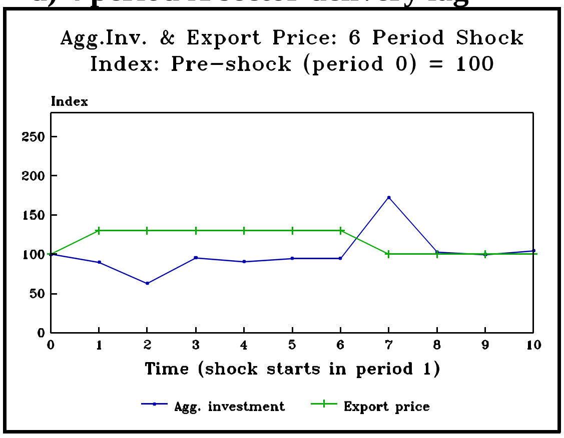


SYMMETRIC INITIAL K_x/K_m

c) 1 period X sector delivery lag

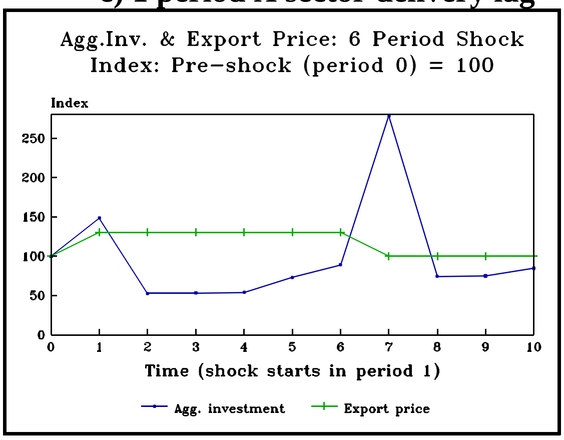


d) 4 period X sector delivery lag

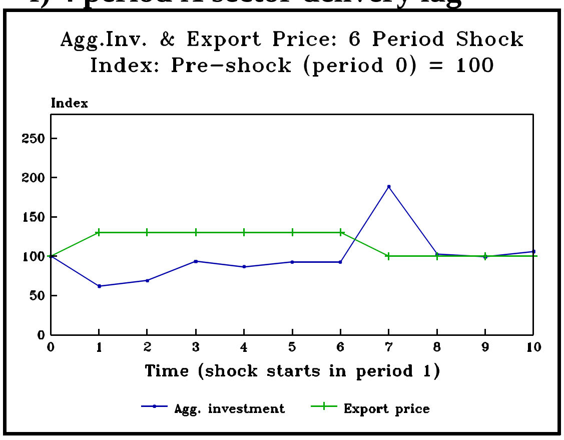


SMALL INITIAL K_x/K_m

e) 1 period X sector delivery lag



f) 4 period X sector delivery lag



In addition the simulations have highlighted possible reasons why the empirical investment literature (see Serven, 1997) has found it difficult to establish a clear relationship between investment and the terms of trade. Such a relationship will exist in the underlying sense that comparing steady states the terms of trade will determine the relative size of the two capital stocks and their combined steady state (replacement) investment will change with that (albeit in an ambiguous direction since relative depreciation rates will be important). In the presence of marked changes in commodity prices, however, investment data will tend to be dominated by changes between steady states rather than the latter themselves. The analysis above shows very clearly that investment in the short run is likely to be a positive function of the absolute change in the terms of trade rather than its level and if price changes are frequent and large such short run effects are likely to predominate. Furthermore the results also indicate that aggregate investment may respond more or less, or not at all, to either upward or downward price movements and the nature of such asymmetries may differ across countries since they depend on relative sector sizes and investment lags.

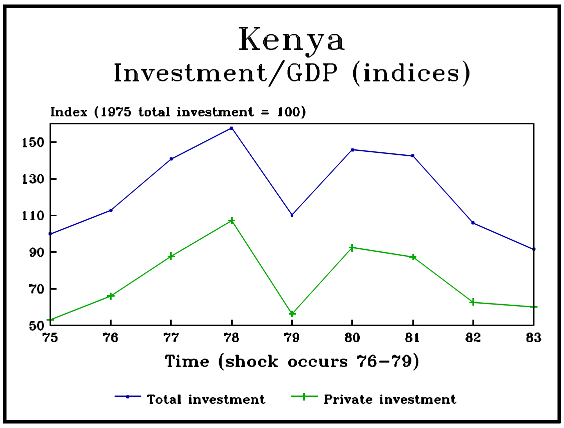
We turn now to a brief examination of some empirical evidence for aggregate investment at the time of the late 1970s coffee and cocoa shocks. This evidence is intended to be indicative rather than conclusive. It was noted above that domestic price controls were in place in many countries at that time and hence the emphasis on relative price changes in the theory above may be less relevant for this period. For this reason we show Collier and Gunning's (1999)[7] attribution of these shocks as "private", "public" or "mixed" which are based on whether the change in world prices largely fed through into domestic prices.

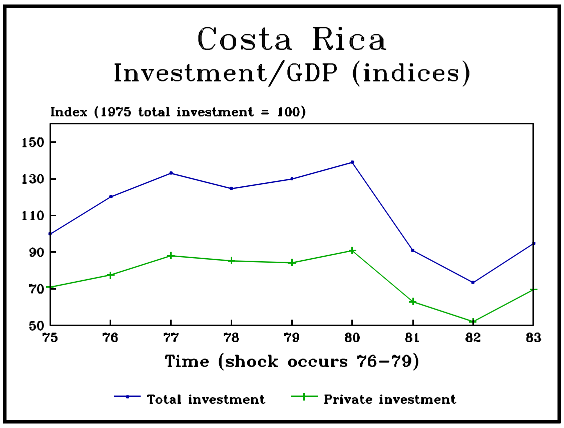
Figure 4 shows both aggregate investment and (where available) private investment for the countries shown, each of which had a four year positive commodity price shock 1976-79,[8] and hence the four year shock simulations of Figure 1 are the natural point of comparison with the theoretical results. Most striking about the charts of Figure 4 is how much more variable is investment generally in the "private" pair of charts at the top, even though they are themselves less jumpy than the theory results which is natural since the model above abstracted from adjustment costs. In addition the private shocks are consistent with the theory since they show some of the "twin peaks" tendency of Figure 1. The total investment/private investment split is helpful here also since the time path of total investment in the top two charts is seen to be driven largely by changes in private investment which is the concern of the theory work. There is some tendency for public investment (the gap between the two lines) to fall towards the end of the period which is to be expected since a fall in export prices is likely to lead to falling revenues.

The mixed shock cases of the middle charts show much less variation over time, aggregate and private investment in Colombia showing some response after the end of the shock in 1979, while aggregate investment in Senegal is unresponsive. The public shock cases of the lower charts show no response to the end of the shock and while private investment is not available for these countries it is likely, given the public nature of the shock, that the aggregate picture is being driven by public investment.

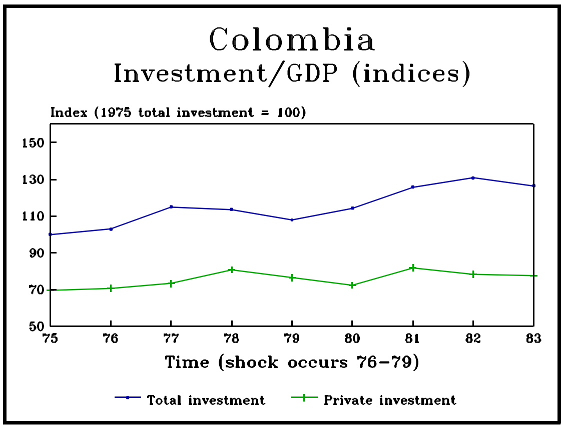
FIGURE 4: EMPIRICAL EVIDENCE, 4 PERIOD SHOCKS

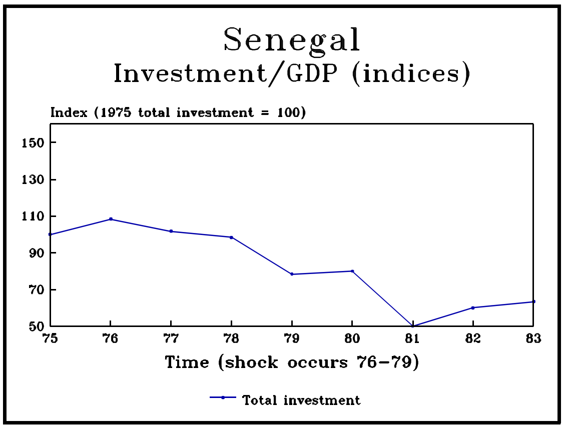
"PRIVATE" SHOCKS



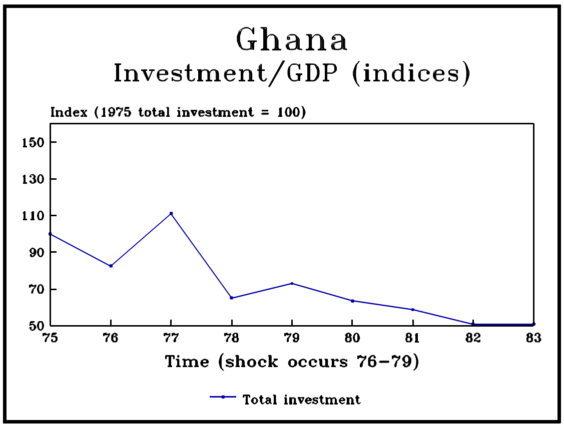


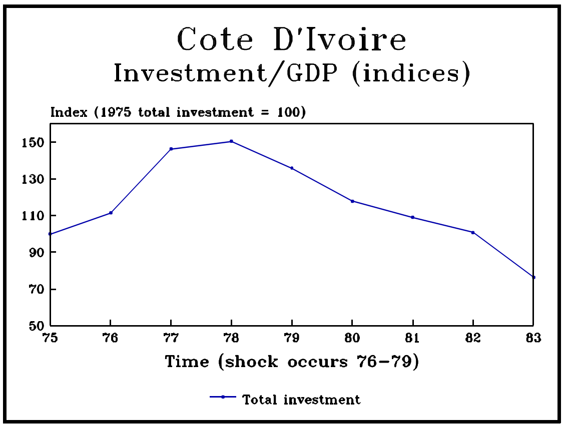
MIXED "PRIVATE/PUBLIC" SHOCKS





"PUBLIC" SHOCKS





3. Feedback Effects From the Investment Response to the World Commodity Price

The material above has been concerned with the investment response to a given, exogenous commodity price shock. Given the information that it has generated about the possible investment (and hence supply) dynamics during and after a shock a question arises as to what that supply response, if repeated across a sufficient number of producers in a world market, might imply on the reverse causation for the time path of the world price. It should be emphasised that the empirical modelling of commodity prices has proved difficult and controversial[9] and requires complexity that is well beyond the scope of this paper. The literature on commodity prices does not appear, however, to have analysed the implications of the irreversible investment response in commodity sectors to large price movements which is the potential contribution of this paper. In particular the nature of the investment response during a shock determines in part the supply response which may affect the world price. In addition, and perhaps more importantly, the nature of irreversible capital is that after the end of a positive price shock, the commodity sector capital stock (and hence to an extent supply, allowing for much quicker movements of labour away from the commodity sector) will tend to fall slowly constrained by depreciation and hence the post-shock level of supply will tend to be higher and thus the world price lower, than before the shock, at least for a few periods until depreciation has restored a steady state.

To illustrate these effects we suppose that the commodity price is determined by:

$$P_x^{\,t} = P_x(1+s)Q_x^{-\frac{1}{\gamma}} \tag{12}$$

In this expression P_x or $P_x(1+s)$ corresponds to the commodity price before/after and during respectively the exogenous price shock analysed above but we now allow the actual P_x that obtains over time to depend also on the level of commodity output Q_x as well as the price elasticity of demand, γ. Hence the source of the price shock, s, remains exogenously imposed but we now allow for a feedback effect from output to the world price while still abstracting from all other sources of price movements. We make the extremely strong assumption that all producing countries are identical in their investment and supply responses, essentially to allow a simple translation between the single country results above and world output which is what influences the world price. Clearly this is unrealistic but our purpose is to illustrate the possible effects generated by the model, particularly in relation to the shape of the price path rather than its exact level, and in that sense a simple exercise of this kind may still be informative. Also for illustrative purposes we assume that the commodity supply responses follow those of the model which amounts to ignoring the further feedback effect from the different price path to different supply responses. The effect of a proper simultaneous determination of output and price may however be seen in general terms from the simulations that follow.

Figures 5-7 below (which correspond to the same cases as Figures 1-3) give the results of taking the earlier supply responses and using them to determine the endogenous price path. In each case the upper line is the simple exogenous price path used earlier while the lower line shows how this changes if the output response alters the price by means of the equation above. The gap between the two lines therefore depends on the supply response of the commodity sector. For the simulations we use a price elasticity of demand of two. Increasing this parameter reduces the gap between the lines but our main interest as before is in the shape of the endogenous price path rather than its exact level and hence the general conclusions drawn are not sensitive to this assumption. Similarly if we allowed for the full simultaneous determination of output and price the lower line would move towards the upper line (since the output response would be lower given expectations that the world output response would lower the commodity price) but again its general shape would not change greatly.

Considering Figure 5 it may be seen that a smaller initial K_x/K_m gives rise to a bigger supply response (a larger gap between the two lines). This is because the commodity sector has a larger pool of labour from the M sector to draw on (more formally the commodity sector can expand employment without wages rising a steeply as if the M sector were smaller) which both increases the immediate supply response due to labour reallocation while also raising the investment response due to the beneficial cross effect on the return to capital of a greater labour movement. Also the supply response and "endogenous" effect on price is smaller for the longer investment lag cases since the commodity sector capital stock both rises less and after a longer delay.

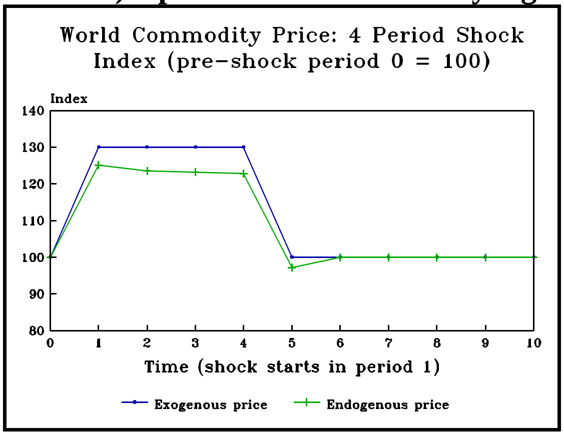
These factors (together with the price elasticity of demand) determine the size of the feedback effect from supply to price but perhaps of greater interest is that the S-shape endogenous price path is broadly similar across the different cases (and in Figures 6-7 except that it is compressed or shrunk according to the duration of the shock). During the shock there is an immediate supply response from labour reallocation and this is followed by an expansion of the commodity sector capital stock (slowly in the 4 period lag cases) which further raises output such that the initial price peak is not sustained. Investment jumps up quickly and then gradually as the M sector capital stock depreciates (shown most clearly in Figure 5(e)) so the supply response builds up at a declining rate over time. After the shock the irreversible nature of the commodity sector capital stock means that its level (and hence in part the output of the commodity) falls only gradually. After the shock there is an immediate reallocation of labour back to the M sector but X sector output nevertheless remains higher (and thus the endogenous price lower) for some time until depreciation allows K_x to reach its steady state.

Once again it should be emphasised that commodity price determination is a difficult area and its proper modelling requires consideration of numerous factors not included above, but to the extent that other factors generate price shocks of the kind examined in the earlier section the feedback effects shown here will exert some influence. Of particular note, perhaps, is that the irreversibility model predicts an overhang of low prices after the end of a positive shock.

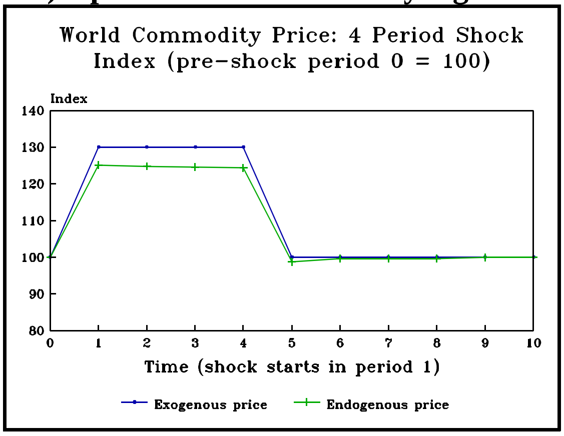
FIGURE 5: WORLD COMMODITY PRICE, 4 PERIOD SHOCK

LARGE INITIAL K_x/K_m

a) 1 period X sector delivery lag

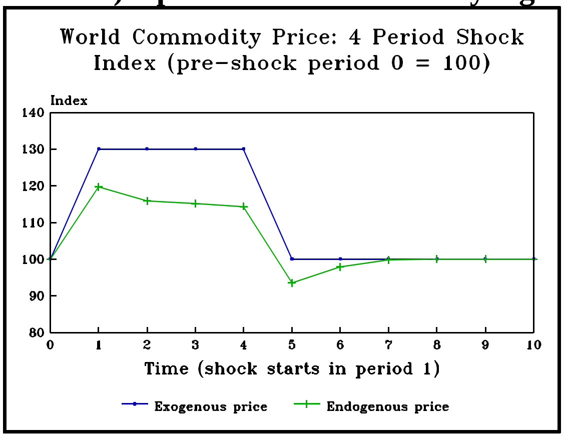


b) 4 period X sector delivery lag

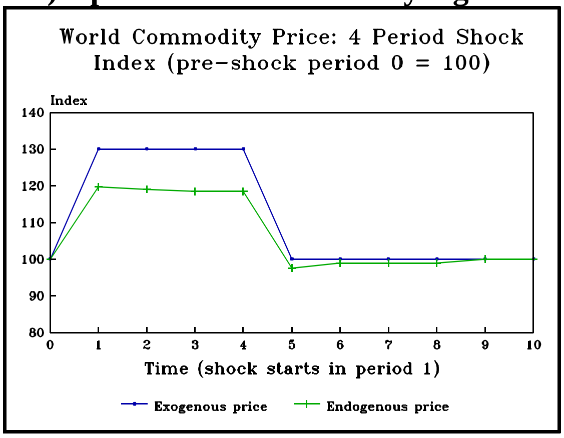


SYMMETRIC INITIAL K_x/K_m

c) 1 period X sector delivery lag

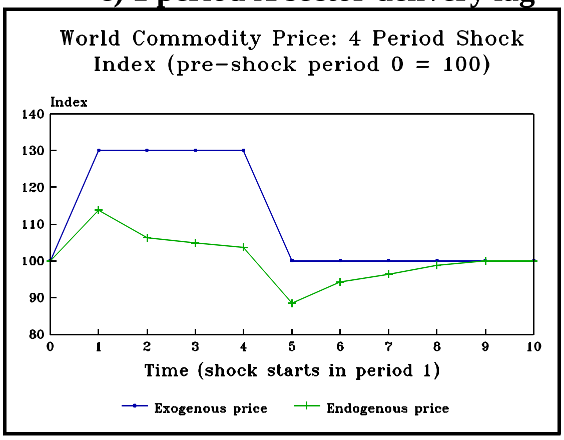


d) 4 period X sector delivery lag



SMALL INITIAL K_x/K_m

e) 1 period X sector delivery lag



f) 4 period X sector delivery lag

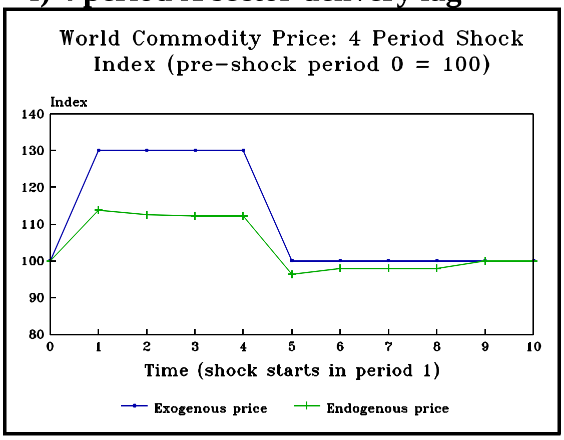
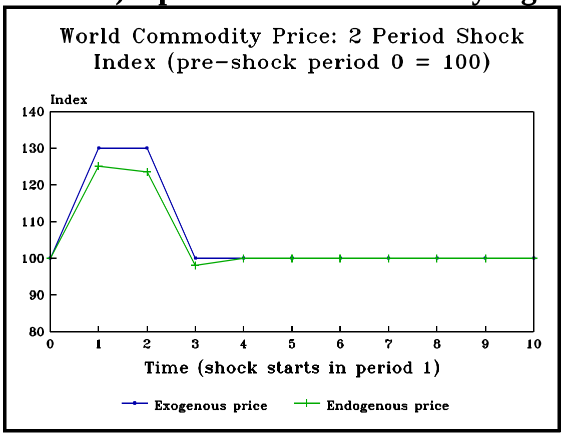


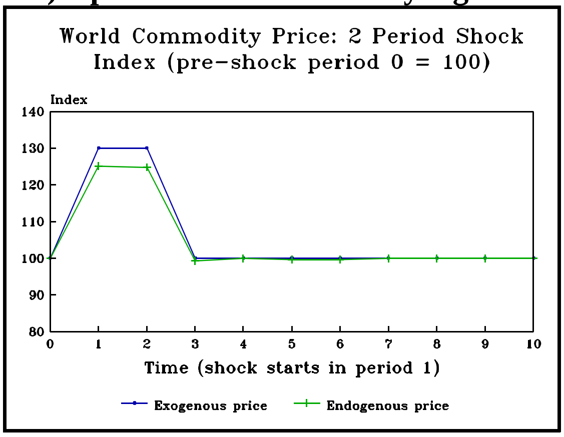
FIGURE 6: WORLD COMMODITY PRICE, 2 PERIOD SHOCK

LARGE INITIAL K_x/K_m

a) 1 period X sector delivery lag

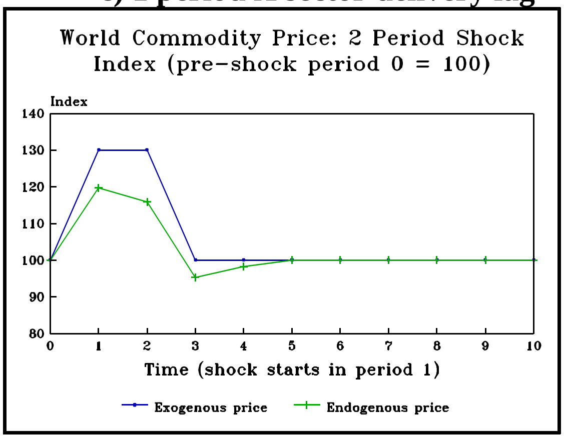


b) 4 period X sector delivery lag

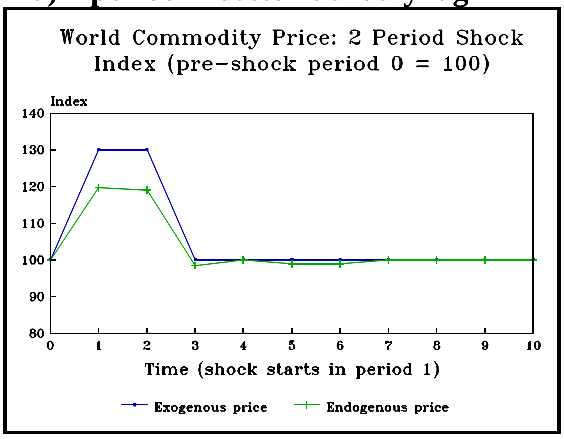


SYMMETRIC INITIAL K_x/K_m

c) 1 period X sector delivery lag

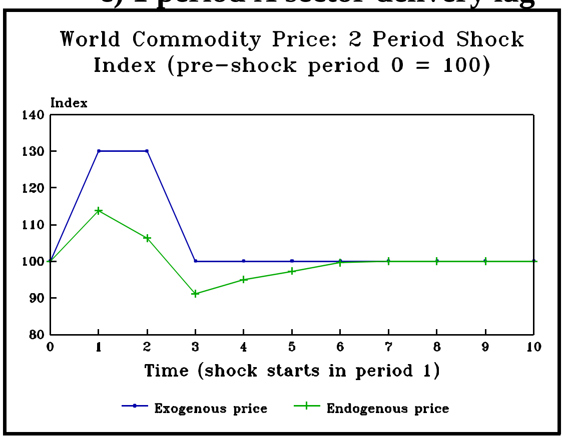


d) 4 period X sector delivery lag



SMALL INITIAL K_x/K_m

e) 1 period X sector delivery lag



f) 4 period X sector delivery lag

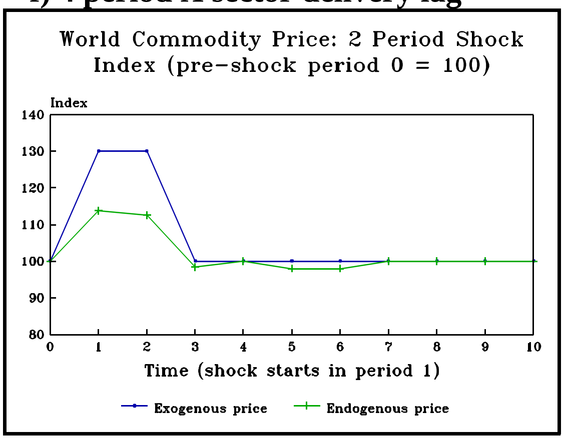
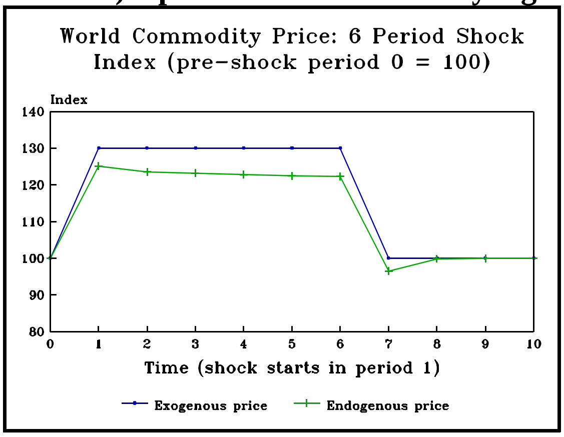


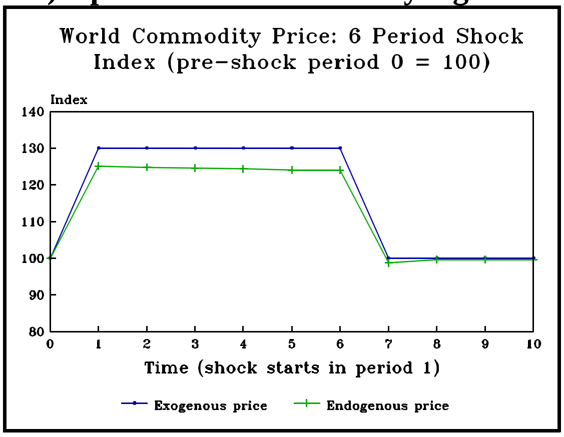
FIGURE 7: WORLD COMMODITY PRICE, 6 PERIOD SHOCK

LARGE INITIAL K_x/K_m

a) 1 period X sector delivery lag

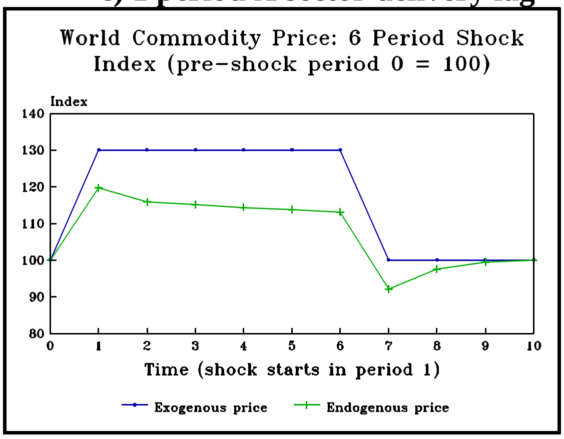


b) 4 period X sector delivery lag

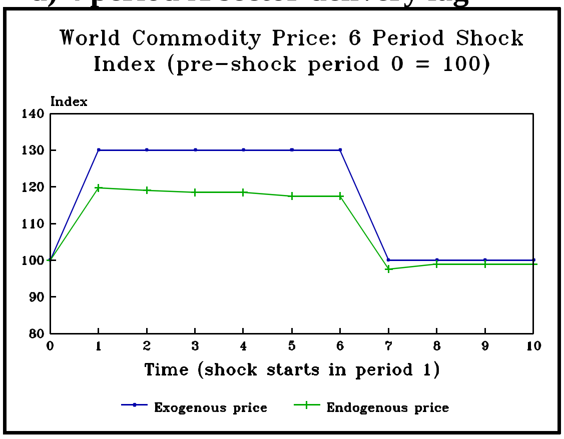


SYMMETRIC INITIAL K_x/K_m

c) 1 period X sector delivery lag

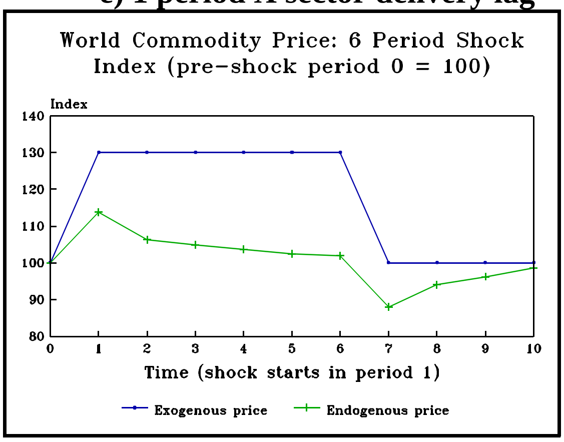


d) 4 period X sector delivery lag

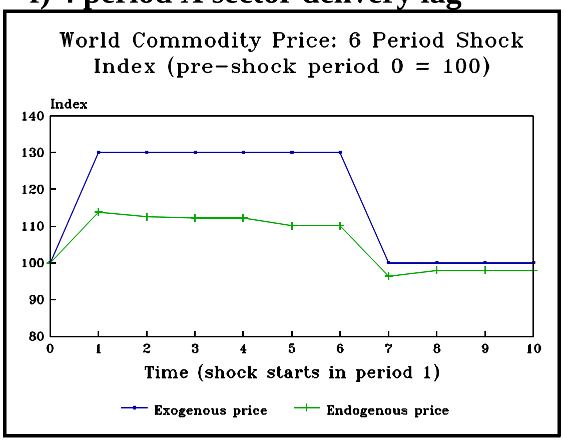


SMALL INITIAL K_x/K_m

e) 1 period X sector delivery lag



f) 4 period X sector delivery lag



4. Financing Constraints on the Investment Response

The final extension to the results presented is a brief consideration of the possible role of financing constraints on the expansion of the commodity sector capital stock during the shock. The formal analysis assumed a perfect world capital market and hence all investment needs could readily be financed at a constant interest rate. If we drop the unrealistic assumption of access to such a market there are a number of possible modelling approaches, a key decision being whether to assume a well functioning domestic capital market (in which national consumption/saving responses to the shock are crucial) or alternatively that this market is also highly imperfect in which case investment must be financed by internally generated funds. We show results for the latter case, since they follow more naturally from the scope of the paper, but assume that the owners of capital can save on the world capital market at the interest rate used above in which case the world interest rate becomes the opportunity cost of funds used for investment. This implies that the investment responses presented earlier are a ceiling on desired investment given that interest rate and we compare the investment outcome with the financing constraint with the earlier results.

In order to generate the financially constrained outcome we need to specify a counterfactual consumption path for the owners of capital during the shock and we adopt the simplest form for this in that it is assumed that consumption continues at the pre-shock level leaving any internally generated funds above this level available for investment. With respect to the latter we present two cases, the first is where new capital must be financed solely from the return to capital itself (relative to the consumption counterfactual for the return to capital only) and the second where the return to both capital and the fixed factor (hence profits if they are both owned by the same agents) is available, relative to the counterfactual consumption level for their combined return.

Figures 8-10 show the simulation outcomes for the unconstrained and constrained capital stocks for these cases while for simplicity considering only symmetric initial sectoral capital stocks. We also consider only the expansion of K_x during the shock since it is more difficult to specify a consumption counterfactual for the subsequent expansion of the M sector capital stock after shock reversal.

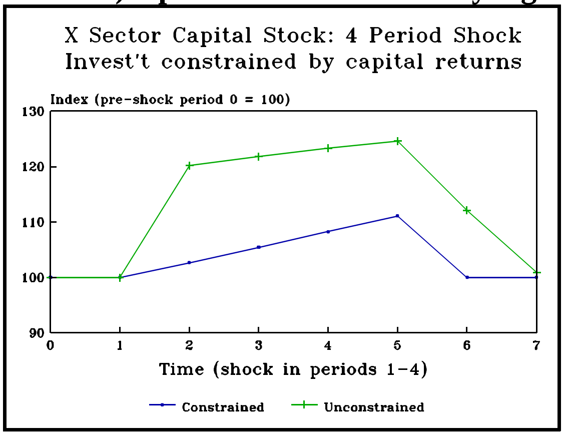
The consistent themes across the figures are that, i) financial constraints do not prevent some investment response, a reflection of the correlation between times when current returns are high and times when irreversible investment is desired, ii) returns from capital only impose a more severe constraint than profits (which is to be expected given the windfall that accrues to the fixed factor in the commodity sector during the shock), iii) that the X sector capital stock approaches or reaches its unconstrained value if the shock persists for long enough, and iv) that the financing constraints are much weaker for the longer investment lag cases. The latter reflects the lower unconstrained expansion combined with the absence of a quick capital stock response which maintains the return to capital at a high level until the new capital goods become productive.

FIGURE 8: FINANCING CONSTRAINTS ON INVESTMENT, 4 PERIOD SHOCK

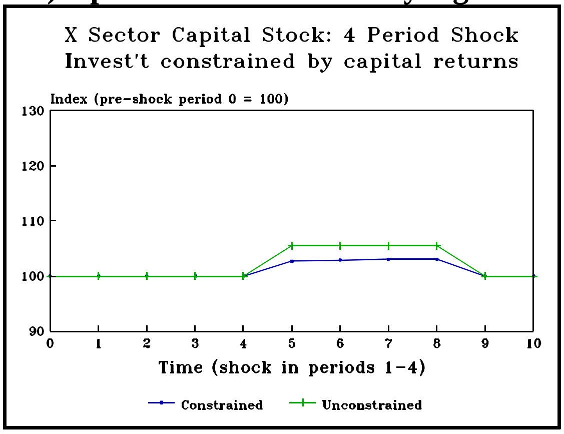
(Symmetric initial K_x/K_m)

X SECTOR INVESTMENT CONSTRAINED BY THE RETURN TO CAPITAL

a) 1 period X sector delivery lag

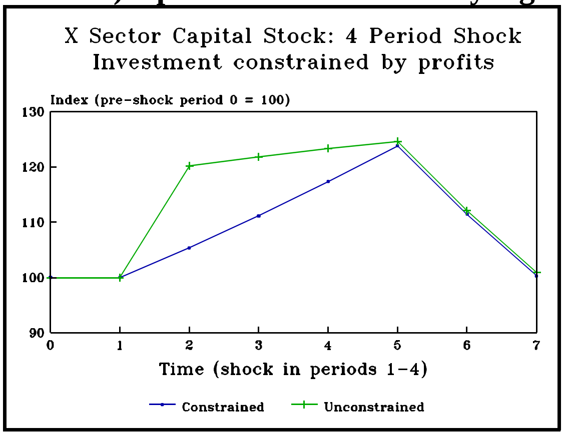


b) 4 period X sector delivery lag



X SECTOR INVESTMENT CONSTRAINED BY PROFITS

c) 1 period X sector delivery lag



d) 4 period X sector delivery lag

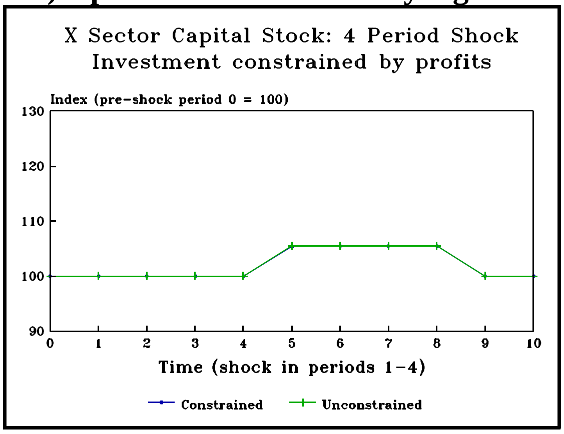
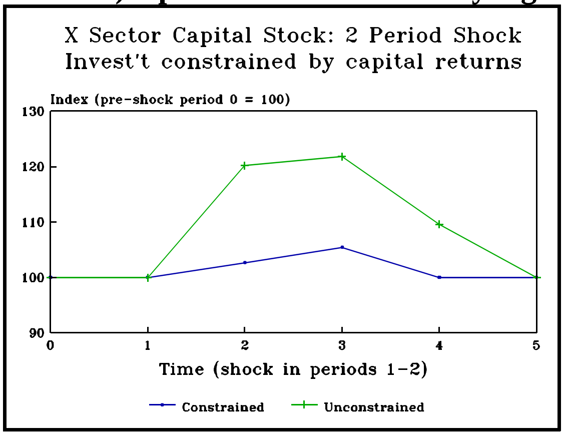


FIGURE 9: FINANCING CONSTRAINTS ON INVESTMENT, 2 PERIOD SHOCK

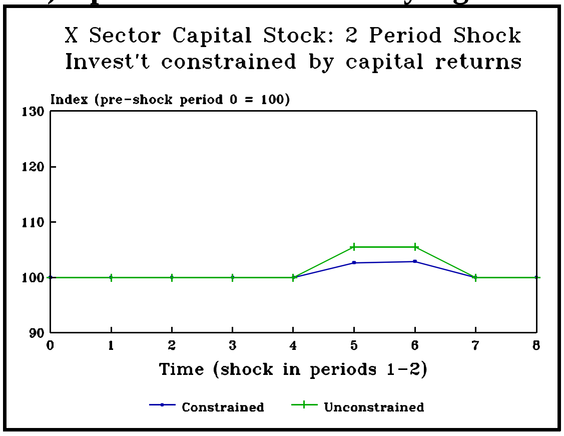
(Symmetric initial K_x/K_m)

X SECTOR INVESTMENT CONSTRAINED BY THE RETURN TO CAPITAL

a) 1 period X sector delivery lag

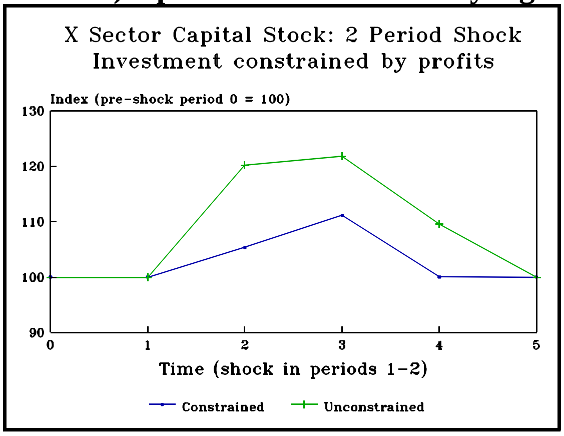


b) 4 period X sector delivery lag



X SECTOR INVESTMENT CONSTRAINED BY PROFITS

c) 1 period X sector delivery lag



d) 4 period X sector delivery lag

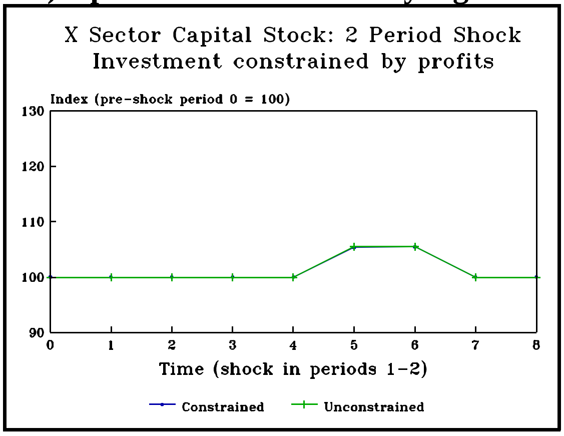
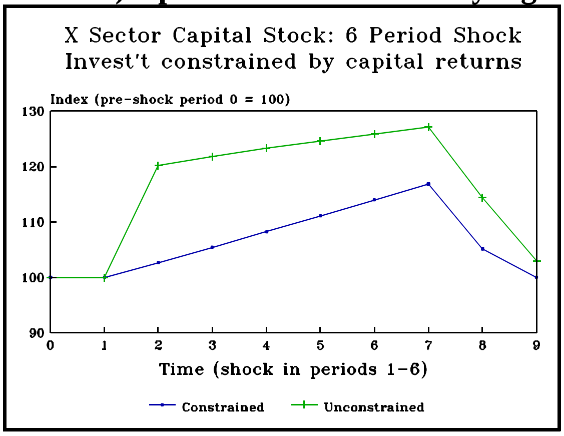


FIGURE 10: FINANCING CONSTRAINTS ON INVESTMENT, 6 PERIOD SHOCK

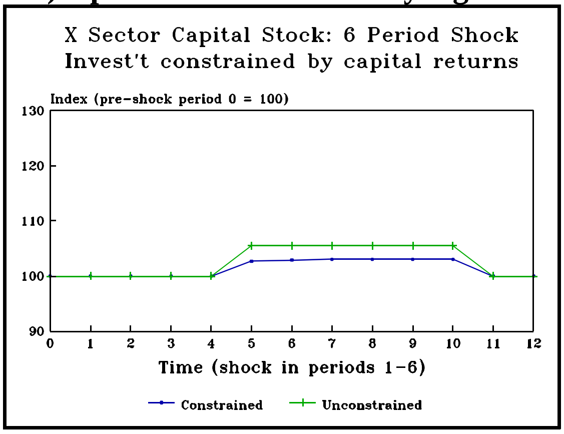
(Symmetric initial K_x/K_m)

X SECTOR INVESTMENT CONSTRAINED BY THE RETURN TO CAPITAL

a) 1 period X sector delivery lag

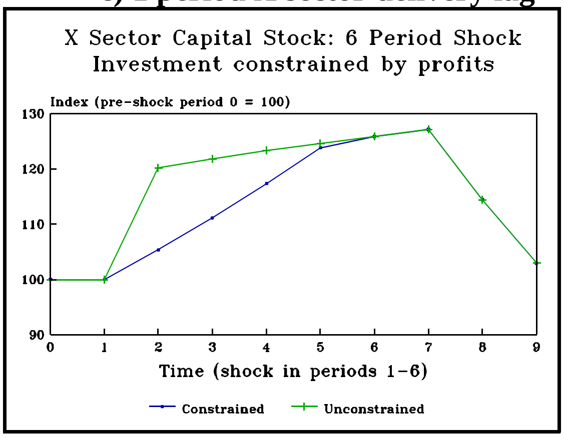


b) 4 period X sector delivery lag

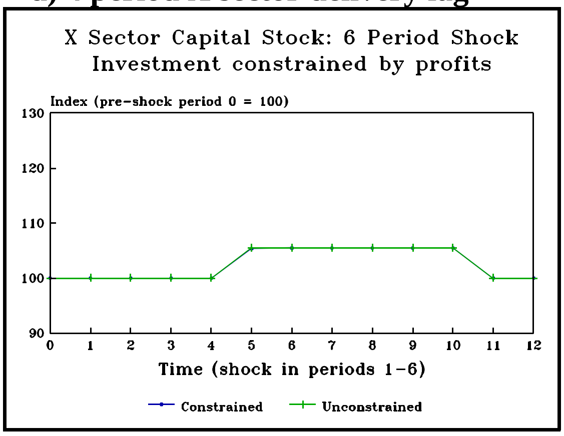


X SECTOR INVESTMENT CONSTRAINED BY PROFITS

c) 1 period X sector delivery lag



d) 4 period X sector delivery lag



5. Conclusion

The paper has analysed the irreversible sectoral and aggregate investment responses to a temporary commodity price shock of uncertain duration. A model was developed based on the insights of the irreversibility and investment literature and used to generate predictions about the likely occurrence and size of investment booms in response to shocks and their reversal. The predictions of the theory were shown to be broadly consistent with some empirical evidence from the late 1970s coffee and cocoa shocks. The implications of the analysis for the empirical specification of investment-terms of trade equations were drawn out, together with possible feedback effects onto world prices from the supply and investment response and an assessment of the importance of imperfect capital markets in constraining that response.

APPENDIX

Parameter, notation and assumed values in simulations

Probability of shock reversal	p	0.25
Proportionate shock size	s	0.3
K_m rate of depreciation	δ_m	0.1
K_x rate of depreciation	δ_x	0.1
World real interest rate	r^*	5%
Share of labour in output (both sectors)	α	0.6
Share of capital in output (both sectors)	β	0.2
Share of permanently fixed factor (both sectors)	$1-\alpha-\beta$	0.2

Relative commodity price, P_x	Symmetric initial K_x/K_m:	P_x set so initial l_x=0.5
	Large initial K_x/K_m:	P_x set so initial l_x=0.75
	Small initial K_x/K_m:	P_x set so initial l_x=0.75

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Notes

1. See Bevan, Collier and Gunning (1990) and Collier and Gunning (1994, 1999).

2. Indeed they may have played a greater role in the mid-90s coffee shock though unfortunately full data to examine this is not yet available.

3. See for example Gavin (1990), Sen and Turnovsky (1995), Serven (1995) and Van Wincoop (1992).

4. Which is plausible, see Deaton (1992) for a wide ranging discussion of this issue.

5. The formal structure of the model is similar to Mash (1998) but with a variable investment delivery lag.

6. Mash (1997) analyses a similar model and see Mash (1998) for further discussion of this expression and a solution procedure close to that which follows (though in a context of ongoing volatility). It may also be noted that for clarity the returns and cost of capital are discounted to period s rather than s-1, given that the expression is equated to zero this makes no difference to the solution obtained.

7. The countries and shock periods are also taken from their sample.

8. Aggregate investment data is from the Penn World Tables, private investment is calculated as a share of this using data from Easterly and Rebelo (1993). I am very grateful to Jan Dehn for this data and many interesting discussions on the analysis of this paper.

9. See Deaton (1992) for an excellent overview of some of the problems encountered. Deaton and Laroque (1992, 1995) and earlier Gersovitz and Paxson (1990) give more detailed results.